THE BOREAL CONIFER ZONE

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By F. Kenneth Hare

The specialist in northern studies is accustomed to frequent shocks when he looks at the world distribution maps. All too often the scholars who draw such maps seem to lose interest when their pens stray north of the limits of dense settlement. Forest-cover, climate, drainage and even coast-lines all suffer. The cartographer not only lacks detailed information, but he makes little use of the sparse data that are available. This is strikingly true, for example, of climatic and vegetation maps of the Soviet Union, which often seem to have been drawn without reference to the abundant Russian sources for such maps, such as the GREAT SOVIET WORLD ATLAS.[1] The fact is that the average geographer is mesothermal in outlook, and devotes little critical attention to the thinly settled, extreme environments that lie beyond the comfortable middle latitudes.

This is especially true of the Boreal lands of the globe, and of the forest that occupies this zone. The vague and unsatisfactory term "coniferous forest" is normally applied to this zone, which on maps, appears as one of the world's largest expanses of undifferentiated surface. Linton's map in the new Oxford Atlas[2] is an honourable exception, for he recognises the separate and unique qualities of the truly boreal coniferous forests, and does not lump them recklessly with the highly mesophytic conifers of, for example, the coast of California and Oregon. Russian authors, too, have been scrupulous in the care with which they treat sub-arctic distributions, a care that springs from the vital significance of this northern territory in their national economy. But British and American authors as a whole have been alike in their undiscriminating attitude towards the Boreal zone.

1. Bol'shoi sovetskii atlas mira (Great Soviet World Atlas) Moscow, 1937-39.
2. THE NEW OXFORD ATLAS, ed. Sir Clinton Lewis and D.J. Campbell, Oxford, 1951, special plates VIII-IX.

To a large extent, this lack of discrimination springs from ignorance. The Boreal forests lie wholly within the territory of Canada, U.S.A. (Alaska), the Soviet Union and the Scandinavian countries (including Finland). Scandinavian and Russian geographers and ecologists have written extensively upon this subject, but their work has been little noted in the British and American journals, in part because of the language barrier. In Canada, where interest ought to have been equally strong, there have until recently been no geographers to carry out the important work of presenting the Boreal environments to the other English speaking countries. The significant body of Canadian research by foresters and forest ecologists has remained little read and little appreciated outside Canada itself. It seems timely, therefore, that a Canadian geographer (by adoption and conviction) should begin, albeit haltingly, a review of the meaning and status of the Boreal zone, and especially of the forest that bears its name.

The adjective Boreal is properly applied to the circumpolar forest that spans Alaska, Canada and Eurasia from Atlantic to Pacific, and occupies the so-called sub-arctic climatic belt; to a reasonable approximation it corresponds climatically to the Köppen subprovinces, Dc and Dd[1], or to the range of potential evapotranspiration 31-52 cm. on Thornthwaite's scale of thermal efficiency.[2]

Within this climatic zone numerical dominance[3] is maintained nearly everywhere by needle-leaved coniferous trees belonging to four genera, pine (Pinus), spruce (Picea), fir (Abies) and larch (Larix); species of hemlock (Tsuga), arbor-vitae (Thuja), juniper (Juniperus) and yew (Taxus) also occur. Broad-leaved hardwood

1. W. Köppen, 'Das geographische System der Klimate', HANDBUCH DER KLIMATOLOGIE, ed. W. Köppen and R. Geiger, Bd. I. Teil C, Berlin, 1936.
2. C.W. Thornthwaite, 'An Approach toward a Rational Classification of Climate', GEOGRAPHICAL REVIEW, 38, (1948), 55-94.
3. Since our knowledge of succession in the Boreal Forest is scanty, precise ecological terminology cannot yet be applied to it as a whole. The term "dominance" here means nothing more than excess in numbers of individuals over other species of the same life-form within the crown layer.

species are usually present as sub-dominant or successional elements in the forest, but achieve apparent dominance in only a few areas. As a rule, these broadleaves belong to the genera willow (Salix), poplar (Populus), alder (Alnus) and birch (Betula), many species attaining only shrub-size.

The term "coniferous forest" so often applied to this zone is ruled out of court by several considerations:-

(1) All the coniferous genera mentioned above have representatives south of the sub-arctic limit: most of their species occur in mid-latitude climates, and are intolerant of sub-arctic conditions. The genus Pinus, for example, possesses only five widespread sub-arctic species (silvestris, sibirica,[4] pumila,[4] contorta[5] var. latifolia and Banksiana), although it possesses 90 species in all, and occurs in tropical forests;

(2) Magnificent coniferous forests occur in temperate and subtropical climates, notably in the Mediterranean area and in western North America. The Pacific forests of the U.S.A. and Canada, for example, are phytogeographically and ecologically distinct from the true Boreal forest, and are confined to the non-Boreal climates of the west;

(3) The Boreal forest, though dominated by coniferous species in most areas, almost always possesses a few broad-leaved species. It is worth adding that the Boreal forest is by no means exclusively evergreen, for a deciduous species of larch is dominant in northeast Siberia, and the deciduous broad-leaf birches are very common in Scandinavia and parts of Labrador-Ungava.

4. Both these species are often regarded as varieties of Pinus Cembra, the stone pine.

5. Pinus contorta, the shore pine, is non-Boreal in distribution.

It may well be asked, in the light of these remarks, whether there is any sound floristic basis for the definition of a distinctly Boreal forest. This forest is, in fact, a climatic differentiate of a once homogeneous high-latitude forest, which in mid-Tertiary times seemed to display no distinct sub-arctic coniferous zone. The Boreal forest was probably selected from its Miocene predecessor by the successive refrigerations of Pleistocene times. On both major continents it seems to have been these glacial ages that introduced strong zonation into the forest cover; in North America it is not, in fact, until the third interglacial that we can demonstrate beyond all doubt that a sub-arctic coniferous forest had been created between the arctic tundra and the mixed or deciduous forest of middle latitudes. The Boreal forest thus originated as a climatic differentiate, and it has remained as such. The only logical basis for its separate recognition is the tolerance on the part of its dominants to short, cool summers and severe, prolonged winter frost.

We shall now proceed to consider the recognisable limits and sub-zones of the Boreal forest, and the apparent climatic correspondences of these lines and belts.

THE ARCTIC LIMIT AND FOREST-TUNDRA

The Boreal forest gives way to Arctic tundra along the Arctic coast of Siberia, Alaska and Canada. It is customary to recognize as this limit the so-called Arctic tree-line which is the line drawn approximately from clump to clump along the extreme poleward limit of tree-growth. The species forming the tree-line may grow as scattered shrubs or in prostrate form beyond it. South of the Arctic tree-line there is a belt of varying width in which tree-growth is confined to the most favourable sites; tundra associations occupy the remaining terrain. This is the Forest-Tundra sub-zone, referred to by some writers as an ecotone, and by others as a belt of interpenetrating

arctic and sub-arctic climaxes.

Many different species form the actual tree-line[1] in Alaska and Canada; white spruce (Picea glauca) predominates in the west, black spruce (P. mariana) in most parts of Labrador-Ungava. The larch (Larix laricina) is the tree-line dominant only in a few districts in Labrador-Ungava, and the pine and fir nowhere attain the tree-line. In Eurasia, by contrast, the larch and pine are very prominent; Pinus pumila and Larix dahurica compete along the limit in northeast Siberia, though P. pumila is usually no more than a shrub. Further west in Eurasia Larix sukaczewii and L. sibirica occasionally outreach Picea obovata, P. Abies and Pinus silvestris. The Arctic tree-line is thus composed of a variety of species with widely differing phytogeographic [2] histories; what unites them, as Hustich shows, is their ecological equivalence, i.e., their nearly identical climatic tolerances.[3]

The earliest-enunciated climatic equivalent for the Arctic tree-line was the isotherm of 50°F. (10°C.) mean daily temperature for the warmest month, suggested by Supan and endorsed by Köppen in his climatic classification. Nordenskjöld[4] later amended this equivalent to

$$w=(9.0-0.1\ k)^{\circ}\text{Centigrade}$$

where w=mean temperature of the warmest month, and k=mean temperature of the coldest month.

The fit was improved, but neither Köppen's line nor Nordenskjöld's amendment really corresponded with the tree-line. The value of 30-33 cm. annual potential evapotranspiration (P-E) in Thornthwaite's scale of thermal efficiency gives a

1. I. Hustich, 'Barrträdsarternas Polara Gränspa Norra Halvklotet' (Polar Limits of the Coniferous Species), COMMUNICATIONES INSTITUTI FORESTALES FENNIAE, 40, (1952), No. 2.
2. The word "phytogeographic" is applied in these pages to studies of the distribution of plants rather than vegetation: this is common botanical usage.
3. I. Hustich, op. cit.
4. O. Nordenskjold and L. Mecking, THE GEOGRAPHY OF THE POLAR REGIONS, American Geographical Society, Special Publications No. 8, (1928), 73.

better fit, and Austin Miller has recently shown that the isopleth with 10°C. (19°F.) of accumulated month-degrees above the 6°C. (43°F.) threshold also fits the tree-line very well.[1]

There is no doubt that the Arctic tree-line is truly a thermal limit. It has been shown[2] that mid-summer temperature (late June, July) is highly correlated in northern conifers with both radial growth and lengthening. Nevertheless, too much should not be expected of the chance coincidence of present biotic limits with climate, for the tree-line is not yet in stable equilibrium in all areas; it can be shown to be migrating in several localities.

The forest-tundra, with its treeless interfluves and woodland patches on the valley floors, stream-banks and pockets of deep soil, is an environment unfamiliar to most geographers. Its name entered English usage from the Russian lyesotundra. Rousseau has recently suggested that it constitutes a distinct biological zone, and cannot properly be regarded as a transition (or ecotone) from Arctic to Boreal zones. He proposes the term "hemiarctic" for this sub-zone.[3] In both major landmasses, the forest-tundra is underlain by widespread permafrost, and displays patterned-ground effects almost as fully as the tundra itself.

THE WOODLAND SUB-ZONE

South of the forest-tundra trees occupy all the mesic sites; the tundra on the interfluves yields to woodland pressing out from the valleys on either hand. The scene does not change at once, however, to forest in the true sense. The

1. A. Austin Miller, 'Three New Climatic Maps, TRANSACTIONS AND PAPERS 1951, No. 17, Institute of British Geographers, 15-20.
2. F.K. Hare, 'Some Climatological Problems of the Arctic and Sub-Arctic', COMPENDIUM OF METEOROLOGY, American Meteorological Society, Boston, 1951, 952-964.
3. J. Rousseau, 'Les zones biologiques de la péninsule québec-Labrador et l'Hémiarctique', CANADIAN JOURNAL OF BOTANY, 30 (1952), 436-474.

structure is chiefly that of open woodland, almost of savannah type, and closed crowns are comparatively rare.

The existence of the boreal woodland zone has been recognized by the Russian and Scandinavian writers for many years; it is clearly identified, for example, by Shishkin on his vegetation map of the Soviet Union,[1] and Halliday indicates a similar zone in Canada.[2] More recently Hustich,[3] Rousseau[4] and the writer[5] have all confirmed the existence of the zone in Labrador-Ungava, and have published maps in considerable detail. Rousseau, incidentally, confines the term "sub-arctic" to this sub-zone, as far as the land-areas are concerned; he also extends the sub-zone into the ocean. Hustich, Dansereau (personal communication) and others also tend to restrict the term "taiga" to the woodland, though the word is applied by most Russian writers to the entire Boreal forest. Rousseau (personal communication) prefers "parkland" to "woodland" for this sub-zone, a usage unlikely to appeal to British students.

The characteristic cover-type of the woodland zone is a sparse, open stand of the dominant conifer or conifers of the district, set in a floor-layer dominated as a rule by lichens like Cladonia, and by shrubs of the genera Betula, Vaccinium, Kalmia and others. The writer has published pictures of the cover-types from Labrador-Ungava,[6] and Berg shows an almost identical type from northern Russia (though he calls it "wooded-tundra").[7]

1. In S.P. Suslov, FIZICHESKAYA GEOGRAFIYA S.S.S.R., Moscow, 1947. See chart of vegetation in folder. 2. W.E.D. Halliday, 'A Forest Classification for Canada', DOMINION FOREST SERVICE BULLETIN, 89, (1937), Department of Resources and Development, Ottawa. See map in folder. 3. I. Hustich, 'On the Forest Geography of the Labrador Peninsula', ACTA GEOGRAPHICA, 10, (1949), No. 2, especially Fig. 20. 4. op. cit. 5. F.K. Hare, 'Climate and Zonal Divisions of the Boreal Forest Formation in Eastern Canada', GEOGRAPHICAL REVIEW, 40, (1950), 615-635. See figs. 8 and 9 for lichen woodland. 6. ibid. 7. L.S. Berg, NATURAL REGIONS OF THE U.S.S.R. (trans. O.A. Titelbaum), New York, 1950, 15-17 (Forest-Tundra); 35-47, especially Fig. 5, (Boreal forest); 53-58 and 63-65 (mixed forests).

The open structure of much of the zone implies vigorous competition between the individual trees, presumably for water, yet the type is very common in excessively wet areas of Labrador-Ungava, where water supply is rarely deficient. The fact that the woodland type also occurs on xeric soils in the forest sub-zone strengthens the conviction that drought and root-zone competition are nevertheless the controlling factors. The writer believes that physiological drought is responsible, rather than drought itself; very low soil temperatures in July, except in the top few inches of soil, lead the trees to adopt a horizontal habit of root development, creating intense competition. Permafrost is unnecessary, though it does exist within the woodland zone in north-west Canada, Alaska and Siberia.

The small but widespread groves of closed-crown forest typical of this zone presumably occupy sites with a deeper layer of high soil temperatures in July.

There have been few attempts to find climatic equivalents for this zone, which usually goes unrecognised in published accounts of the Boreal forest. In Labrador-Ungava the writer has shown that the southern limit of the forest-tundra lies close to the Thornthwaite thermal efficiency isopleths of 33-35 cm.,[1] and the northern limit of the closed-crown Boreal forest lies near the isopleth of 43 cm. In the Soviet Union west of the Yenisei, the woodland zone as mapped by Shishkin[2] lies between the isopleths of 35 cm. and 41 cm., a range slightly less than in Canada. Elsewhere the status of mapping is low, and climatic data are too sparse to attempt further extension of this correlation. There is little doubt, however, that the sub-zone is thermally controlled; availability of rainfall seems to have no bearing upon its position.

Much of the woodland sub-zone in Canada and the western part of the Soviet Union is badly drained, and intrazonal "muskeg" (i.e., spruce or pine swamps) and bog occupy vast areas. Only on the mesic sites is the woodland structure fully developed.

1. F.K. Hare, op. cit, (GEOGRAPHICAL REVIEW, 1951). 2. op. cit.

THE CLOSE FOREST SUB-ZONE

The southern sub-zone of the Boreal forest is predominantly a closed-crown forest, with a densely shaded floor. This is the principal source of economic timber and pulpwood, and is much more thoroughly explored than the preceding sub-zones. Open woodland types of the type described above occur, but are confined as a rule to the xeric sites, usually sandplains; well-known are the bors of the Soviet Union, dominated by Scots Pine (pinus silvestris), and similar types occur in Canada with Jack Pine (Pinus banksiana) and spruce (Picea glauca or mariana) forming the open cover. Overwhelmingly, however, this is the land of the gloomy, impenetrable spruce and fir forests that form the substance of almost all existing accounts of the Boreal forest.

Patches of close forest occur within the woodland zone almost to the forest-tundra limit, but the forest sub-zone[1] can be regarded as limited on the north by the line on which close forest stands occupy at least 50% of the mesic sites. Efforts are being made in eastern Canada to map this generalised boundary precisely, but elsewhere its position is only approximately known.

It is of some interest to note that Rousseau regards the forest sub-zone as belonging biotically to the temperate forests in spite of its floristic similarities to the woodland sub-zone; in effect, he disputes the existence of a Boreal forest including all the northern coniferous sub-zones, which to him are entirely distinct from one another. We have seen already that he confines the term sub-arctic to the woodland, a view followed by Dansereau (personal communication) and some Russian authors.

1. For Rousseau, the floristic similarities are more apparent than real. According to him, that impression of similarity is given by the presence of black spruce on both sides and, if we except this tree, there are several differences in the flora between the two.

THE SOUTHERN BORDER AND ADJACENT FORMATIONS

The Boreal forest in northern Europe passes southwards into a temperate mixed forest along a striking ecological boundary called the Limes norrlandicus by Scandinavian ecologists. Much attention has been given to this boundary because, among other things, it played a significant role in prehistory, notably in late mesolithic and neolithic times. It runs from southern Norway and Sweden east-south-eastwards to the Urals, passing about 150 miles north of Moscow. Along this limit, oak (Quercus robur), linden (Tilia cordata), maple (Acer platanoides) and ash (Fraxinus excelsior) replace the dominant conifers of the Boreal forest, though spruce (Picea Abies) and pine (Pinus silvestris) remain common. Cutting has increased the proportion of softwood admixture.

Between the Urals and the Ob', the Boreal forest confronts the central Asiatic steppes in a broad forest-steppe ecotone dominated by aspen (Populus tremula) and birch (Betula pubescens; B. verrucosa) groves set in parkland strikingly like that of Saskatchewan and Alberta. A similar junction occurs in central Siberia, but here the complex, mountainous relief makes generalisation verge on the impossible. In the Far East, however, a normal contact is reestablished in the Amur valley, where the Boreal forest is in sharp contact with a temperate mixed forest dominated by Mongolian oak (Quercus mongolica), containing abundant ash, walnut, birch and linden of Manchurian phytogeographic type, as well as spruce and pine.[1]

In North America four distinct sections of the Boreal limit can be recognised. In a few areas of the Alaskan south coastal district, typical Boreal forest is in contact with the northern outliers of the Pacific Coast forest of Canada and the U.S.A.; white and black spruce yield to Sitka spruce (Picea sitchensis) and other non-Boreal conifers having a wide mesothermal distribution in British Columbia

1. L.S. Berg, op. cit.

and the Pacific Northwest of the U.S.A. Further east in Alaska and in Yukon and Mackenzie (Canada), the contact is with the sub-alpine forest of the western cordillera, a forest occupying the mountain belt high enough to have a Boreal temperature cycle, but nevertheless phytogeographically distinct from the Boreal forest.

In the Prairie Provinces of Canada, the dry interior climate leads to a marked change. In the Mackenzie, Liard and Peace drainage basins, the Boreal forest itself displays a differentiation traceable to low rainfall; white spruce attains its greatest size, but is hard put to it to maintain dominance over the poplars. Grassy openings occur in many areas, and soil pH tends towards alkaline values. This droughty differentiate of the normal forest confronts the Prairies in a broad forest-steppe ecotone, containing numerous aspen groves (Populus tremuloides) akin to those of western Siberia.

Still further east, the Boreal forest passes southwards into a mixed forest of a type very similar to that of the Amur valley and eastern Europe, though richer in species. The boundary runs from Lake Winnipeg to Lake St. John and the Gaspé; the Maritime Provinces lie south of it, and Newfoundland is on or north of it. Hustich has proposed the term Limes labradoricus for this important boundary (personal communication) by analogy with the Limes norrlandicus. It marks the rapid change from the typical spruce-balsam fir forest of the Boreal zone to a forest dominated by sugarmaple (Acer saccharum) yellow birch (Betula lutea), white and red pine (Pinus strobus; P. resinosa) and species of oak, beech, ash, linden (basswood), hemlock, spruce and many others.

The climatic correspondences of this circumpolar boundary are reasonably easily demonstrated. The limit is obviously under thermal control; Miller, for example, correlates it with the line along which only six months have a mean daily temperature above 43°F. (6°C.).[1] This line deviates from the southern boundary by

1. op. cit.

a considerable amount at several points. The best fit seems once again to be with Thornthwaite's thermal efficiency index (potential evapotranspiration, P-E). The following approximate correlations are suggested for the humid sections of the limit where temperature mixed forest borders the Boreal zone:

Limes norrlandicus	Limes labradoricus	Manchu-Amur forests
P-E (cm.)		
53	51	51

The forest-steppe boundary visible in western Siberia and in the Canadian Prairie Provinces is, of course, controlled by aridity rather than the thermal régime. Curiously enough, the forest-steppe boundary in both regions is close to the normal, thermal limit of the Boreal forest; north of this limit, coniferous and mixed forest is able to survive at aridities (i.e., excess of water need over available precipitation) as great as those recorded in the grasslands to the south. It looks as if coniferous forest can maintain itself at aridities that compel deciduous broad-leaved forest to yield to the grasslands.

SUB-ALPINE FORESTS IN MID-LATITUDES

We have already glanced at the distribution of non-Boreal coniferous forest in truly temperate latitudes. It remains, however, to discuss very briefly the sub-alpine forests that occur on high midlatitude mountains in the altitudinal belt corresponding thermally to the Boreal zone. These forests bear a strikingly close correspondence to the Boreal forest ecologically, though they are floristically distinct, and have a different phytogeographic history. Spruce, pine, fir and larch remain as dominant elements, even in the sub tropics, a well developed pine forest for example, occupies high altitudes on the Haitian mountains, in latitude 18½°N.,[1] though Rousseau (personal communication) likens this forest to the New Jersey sand-barren forests rather than the Boreal forest.

1. Fr. Marie-Victorin, 'Les Hautes pinédes d'Haiti', CONTRIBUTIONS DE L'INSTITUT BOTANIQUE DE L'UNIVERSITE DE MONTREAL, 48, (1943), 47-60. See also CANADIAN NATURALIST, 70 (1943), 245-248.

There are structural differences between Boreal and sub-alpine types. The forest-tundra in the latitudinal zonation is replaced below the alpine tundra by prostrate conifers intermingled with alpine meadows, and the open-structured woodland zone is represented by the tangled thickets known as krummholz These remarks are true, at least, in windy regions known to the author. In those rare regions where high mountain slopes are sheltered against strong winds, the sequence more closely resembles the Boreal zonation, though the author has not seen lichen-woodland structure in sub-alpine forest; Rousseau (personal communication) reports an instance in the Otish Mountains of northern Quebec.

All the high mountain belts of mid-latitudes can produce examples of this sub-alpine type; the Alps, Himalayas and other mountains of the Tethys belt possess a remarkable suite of endemic species of pine, spruce, fir and other conifers adapted to these conditions. But it is in North America that the sub-Alpine forests have been best studied and understood.

On the Rockies, Coast Ranges and other high mountains of the western cordillera of North America, the sub-alpine forest is dominated by Engelmann spruce (Picea Engelmanni), alpine fir (Abies lasiocarpa) and lodgepole pine (Pinus contorta var. latifolia) resembling ecologically the white spruce, balsam fir and jack pine of the nearby Boreal forest. These specific differences reflect the differing Pleistocene histories of the Boreal forest; the sub-alpine forest of the Cordillera presumably consists of species that took refuge in the south-western U.S.A. during the Pleistocene cold, whereas the Boreal dominants are believed to have survived in "Beringia" and eastern refuges.[1] The two forests meet in a broad transition zone across northern British Columbia and the Yukon.[2]

1. See H.M. Raup, 'Botanical Problems of Boreal America', BOTANICAL REVIEW, 7, (1941), 147-248. E. Hultén, FLORA OF ALASKA AND YUKON, 8 Vols., Lund, 1941-1948, and E. Hultén, OUTLINE OF THE HISTORY OF ARCTIC AND BOREAL BIOTA DURING THE QUATERNARY PERIOD, Stockholm, 1937.
2. W.E.D. Halliday, op. cit.

The eastern Cordillera also displays sub-alpine forest on the high summits. The spruce-fir forest of Gaspé and highlands of New England is simply a southward extension of the main Boreal forest. The sub-alpine forests of the southern Appalachians, however, are floristically distinct. Red spruce (Picea rubens) and Fraser balsam fir (Abies Fraseri) cover large areas of the high summits in the Great Smokies and other ranges. The relations of this forest are obscure, the genetic and phytogeographic history of the fir is as yet undetermined as is its relationship to the balsam fir (Abies balsamea) of the Boreal forest.[1] The red spruce is also a puzzle, as it has a wide distribution at low altitudes of the mixed forest of the Maritime Provinces of Canada and of New England; it does not seem able to invade the Boreal zone.

MAPS OF THE BOREAL FOREST

No map of the Boreal forest is known to the author that takes adequate account of (i) the ecological uniqueness of the forest, (ii) its relationship to sub-alpine and temperate coniferous forests, (iii) its zonal sub-divisions and (iv) its physiognomy and structure. For North America the maps of Halliday, Hustich, Rousseau and the author give the necessary detail, and over Eurasia the maps of Shishkin and other Russian authors are available.[2] Most botanists who have worked on the Boreal zone have been phytogeographers interested in the distribution of individual species, rather than the forest itself, and its climatic status. Thus the magnificent maps of E. Hultén and his detailed published works on the flora of Alaska and northern Europe[3] can be interpreted

1. E.S. Deevey, Jr., 'Biogeography of the Pleistocene', BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA, 60, (1949), 1315-1416, reference on p. 1375 to Abies Fraseri. 2. Reference to all of these has been made above. (Hare, GEOGRAPHICAL REVIEW, 1950; Hustich, ACTA GEOGRAPHICA, 1949). 3. In addition to his FLORA OF ALASKA AND YUKON see also his ATLAS OF THE DISTRIBUTION OF VASCULAR PLANTS IN NORTH-WEST EUROPE, Stockholm, 1950.

ecologically only with difficulty. The same is true of the work of Raup on the Canadian Northwest,[1] though Raup makes the interpretation far easier because of his awareness of the ecological force of what he writes. Finally it may be added that cross-correlation between Eurasia and North America has been made easier and far more certain by the work of Ilmari Hustich[2] who has worked extensively on the Finnish and Labradoran sectors of the forest. Both Hustich and Rousseau take the broad, world viewpoint necessary for ultimate success, and both take physiognomy as their fundamental yardstick.

Two recent attempts at a world-wide synthesis deserve our attention:

(1) Linton's excellent world vegetation map in the New Oxford Atlas,[3] is one of the rare compilations that recognize the Boreal forest as a distinct, climatically-controlled zone, and his map is commendably detailed. Over North America, the map is correct in detail and in classification, though it does not recognise the zonal sub-divisions. Over Eurasis the general lineaments are sound, but the classification can be challenged. Linton refers the southern half of the Boreal forest to "northern mixed forest", thus grouping it with the predominantly broadleaved mixed forests of western Russia, Poland, Germany and the Great Lakes-St. Lawrence districts of North America; it is quite clear from the accounts of Berg and others that this zone should properly be referred to Linton's "Boreal mixed forest" or Boreal coniferous forest, for it contains no temperate species, and closely resembles the forests of northern Saskatchewan and Alberta (referred to the "Boreal mixed forest" by Linton). The effect of Linton's classification is to expunge the Russian section of the Limes norrlandicus from the map, and to group (for example) the thin larch-scrub pine

1. H.M. Raup, 'Phytogeographic Studies in the Athabaska-Great Slave Lake Region', JOURNAL OF THE ARNOLD ARBORETUM, 27 (1946, 1-85 especially p. 69. Many other papers by the same author also deal with north-west Canada. 2. op. cit., ACTA GEOGRAPHICA, 1949. 3. op. cit.

forests of Yakutiya with the magnificent maple-beech-white pine stands of the St. Lawrence valley.

(2) The map of A.W. Küchler,[1] though less detailed, is the soundest available. Its approach is physiognomic, and the author's methods are precise and consistent. Accordingly, the Boreal forest stands out as needle-leaved evergreen forest or needle-leaved deciduous forest (the larch region of N.E. Siberia). The three areas of temperate mixed forest (Great Lakes-St. Lawrence-Acadian, Northern Europe and the Amur-Manchu forests) are clearly shown and differentiated, and all the Boreal limits are accurately mapped, though there is no attempt to identify zonal sub-divisions. Küchler's physiognomic approach makes it impossible, however, for him to separate the Boreal forest from the

1. A.W. Küchler, Map of World Natural Vegetation in GOODE'S SCHOOL ATLAS (revised E.B. Espenshade), Chicago, 1950, 16-17.

ub-alpine and Pacific Coast forests of western North America.

It is clear that we have not yet reached the point at which agreement on oreal classification can be expected, and acceptable maps of the zone's forest over must await further debate and further survey. The present brief review ill be brought to a close by some summary conclusions, illustrated by a highly entative map:

1) The Boreal zone is a climatically determined unit which is everywhere occupied (except in settled areas) by a conifer-dominated forest:

2) This forest is dominated by distinct, cold-tolerant species of Picea, Pinus, Abies and Larix, most of whose other species are non-Boreal in distribution;

3) Coniferous forests occur widely outside the Boreal forest, and the latter term is hence preferable to "coniferous forest" as a name for the unit under discussion;

4) The Boreal forest occupies a distinct, roughly latitudinal zone, whose limits seem to correspond best to isopleths of Thornthwaite's thermal efficiency:

5) The forest also displays a tendency towards a threefold zonal sub-division. These sub-divisions are primarily structural or physiognomic. Like the limits of the forest itself, they appear to be thermally controlled, and correspond most closely to isopleths of the thermal efficiency index [illegible] approximate correlations are as follows:-

Zone	Name	Values of PE
-	Tundra	Tundra
		30 33
3	Forest-Tundra	Tundra on interfluves, woodland in valleys. Rousseau's "hemiarctic".
		33 35
2	Woodland	Lichen-woodlands with less than 50% admixture of closed-crown forest. Rousseau's "sub-Arctic"; Dansereau's "taiga."
		41 43
1	Close Forest	Closed crown forest occupying at least 50% of the mesic sites.
		51 53
	Mixed Temperate Forests, etc.	Forest dominated by species of non-Boreal types, usually deciduous broadleaves

Fig. 2 shows the limits of these climatic sub-divisions (derived from the table's middle column). The lines are drawn from values of potential-evapotranspiration computed by the staff of the Johns Hopkins Laboratory of Climatology (Eurasia) or by the author (North America). The actual values employed were as follows:-

Zone 3/Tundra — 31 cm.

Zones 2/3 — 35 cm.

Zones 1/2 — 42 cm.

Zone 1/Temperate — 52 cm.

Fig. 2 is not a vegetation map. It shows purely a climatic zone — in this case, a thermal zone computed by means of a recently-developed efficiency index which purports to be a measure of the stimulus offered to growth. The map is put forward in the belief that the Boreal forest is essentially a response to a specific climate. It may help ecologists, geographers and others towards a more general agreement on boundaries, classification and sub-division.

(6) The term "sub-arctic" is confusing, and should, in the author's view, be abandoned. Köppen, Rousseau and Hustich have all given it different meanings, and its retention in formal classification is pointless, though it will continue to serve as a qualitative indicator of the cold lands. There is, however, little prospect that the term will disappear; if we must retain it, the usage of Rousseau, who applies it to the woodland sub-zone, seems soundest.

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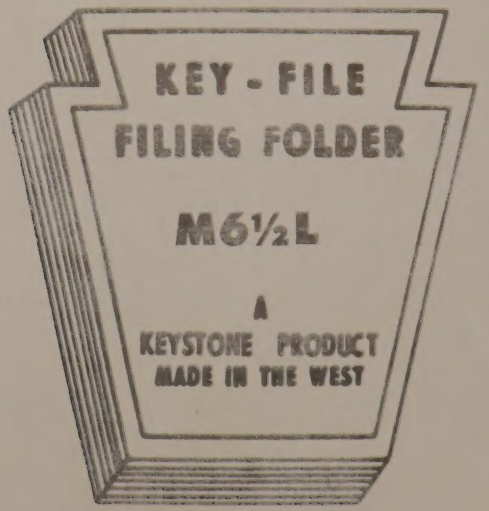
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